Problem 1
The turbine is an open system. We identify the steam contained the turbine as the control volume.

Mass conservation:
\[
\frac{dm}{dt} - \dot{m}_1 + \dot{m}_2 + \dot{m}_3 = 0
\]

1st law of thermodynamics:
\[
\frac{dE}{dt} = \dot{m}_1 \left( h_1 + \frac{V_1^2}{2} + gz_1 \right) + \dot{m}_2 \left( h_2 + \frac{V_2^2}{2} + gz_2 \right) + \dot{m}_3 \left( h_3 + \frac{V_3^2}{2} + gz_3 \right) = \dot{Q}_m - \dot{W}_s
\]

Assumptions:
- Steady state: \( \frac{dm}{dt} = \frac{dE}{dt} = 0 \)
- Neglect changes in kinetic energy and potential energy
- Isentropic process: \( \dot{Q}_{in} = 0 \)

Reduced equations:
\[
-\dot{m}_1 + \dot{m}_2 + \dot{m}_3 = 0
\]
\[
-\dot{m}_1 h_1 + \dot{m}_2 h_2 + \dot{m}_3 h_3 = -\dot{W}_s
\]

Since \( \dot{m}_3 = 0.05\dot{m}_1 = 0.1 \text{ kg/s} \), the first equation yields: \( \dot{m}_2 = 0.95\dot{m}_1 = 1.9 \text{ kg/s} \).

Enthalpy determination:
At the outlet 2: \( P_2 = 50 \text{ kPa} \), \( T_2 = 100^\circ C \) (superheated vapor since \( T_2 > T_{sat,50 \text{ kPa}} \))

Using the superheated vapor table:

<table>
<thead>
<tr>
<th>( T )</th>
<th>( v )</th>
<th>( u )</th>
<th>( h )</th>
<th>( s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td>m³/kg</td>
<td>kJ/kg</td>
<td>kJ/kg</td>
<td>kJ/kg.K</td>
</tr>
<tr>
<td>Sat.¹</td>
<td>3.2403</td>
<td>2483.2</td>
<td>2645.2</td>
<td>7.5931</td>
</tr>
<tr>
<td>50</td>
<td>3.4187</td>
<td>2511.5</td>
<td>2682.4</td>
<td>7.6953</td>
</tr>
<tr>
<td>100</td>
<td>3.8897</td>
<td>2585.7</td>
<td>2780.2</td>
<td>7.9413</td>
</tr>
<tr>
<td>150</td>
<td>4.3562</td>
<td>2660.0</td>
<td>2877.8</td>
<td>8.1592</td>
</tr>
<tr>
<td>200</td>
<td>4.8206</td>
<td>2735.1</td>
<td>2976.2</td>
<td>8.3568</td>
</tr>
<tr>
<td>250</td>
<td>5.2841</td>
<td>2811.6</td>
<td>3075.8</td>
<td>8.5387</td>
</tr>
<tr>
<td>300</td>
<td>5.6988</td>
<td>2889.3</td>
<td>3176.4</td>
<td>8.7096</td>
</tr>
<tr>
<td>350</td>
<td>6.0297</td>
<td>2968.9</td>
<td>3279.3</td>
<td>8.8559</td>
</tr>
<tr>
<td>400</td>
<td>6.3680</td>
<td>3051.5</td>
<td>3383.9</td>
<td>8.9855</td>
</tr>
<tr>
<td>450</td>
<td>6.6966</td>
<td>3135.8</td>
<td>3489.3</td>
<td>9.0997</td>
</tr>
<tr>
<td>500</td>
<td>7.0044</td>
<td>3222.0</td>
<td>3597.0</td>
<td>9.2004</td>
</tr>
<tr>
<td>550</td>
<td>7.2989</td>
<td>3309.3</td>
<td>3706.0</td>
<td>9.2822</td>
</tr>
<tr>
<td>600</td>
<td>7.5897</td>
<td>3397.6</td>
<td>3816.0</td>
<td>9.3557</td>
</tr>
<tr>
<td>650</td>
<td>7.8766</td>
<td>3487.0</td>
<td>3927.9</td>
<td>9.4201</td>
</tr>
<tr>
<td>700</td>
<td>8.1940</td>
<td>3585.5</td>
<td>4040.4</td>
<td>9.5683</td>
</tr>
<tr>
<td>750</td>
<td>8.4994</td>
<td>3685.2</td>
<td>4156.4</td>
<td>9.7000</td>
</tr>
<tr>
<td>800</td>
<td>8.7959</td>
<td>3785.8</td>
<td>4274.2</td>
<td>9.8083</td>
</tr>
<tr>
<td>850</td>
<td>9.0862</td>
<td>3887.4</td>
<td>4392.2</td>
<td>9.9070</td>
</tr>
<tr>
<td>900</td>
<td>9.3727</td>
<td>3988.9</td>
<td>4512.7</td>
<td>10.007</td>
</tr>
<tr>
<td>950</td>
<td>9.6579</td>
<td>4091.4</td>
<td>4635.7</td>
<td>10.107</td>
</tr>
<tr>
<td>1000</td>
<td>9.9337</td>
<td>4194.8</td>
<td>4760.7</td>
<td>10.207</td>
</tr>
<tr>
<td>1050</td>
<td>10.2080</td>
<td>4299.2</td>
<td>4887.7</td>
<td>10.307</td>
</tr>
<tr>
<td>1100</td>
<td>10.4784</td>
<td>4405.3</td>
<td>5017.7</td>
<td>10.407</td>
</tr>
<tr>
<td>1150</td>
<td>10.7482</td>
<td>4512.2</td>
<td>5150.7</td>
<td>10.507</td>
</tr>
<tr>
<td>1200</td>
<td>10.9983</td>
<td>4620.0</td>
<td>5286.7</td>
<td>10.607</td>
</tr>
<tr>
<td>1250</td>
<td>11.2481</td>
<td>4728.7</td>
<td>5424.7</td>
<td>10.707</td>
</tr>
<tr>
<td>1300</td>
<td>11.4978</td>
<td>4838.3</td>
<td>5565.7</td>
<td>10.807</td>
</tr>
</tbody>
</table>

\( h_2 = 2682.4 \text{ kJ/kg} \)

\( s_2 = 7.6953 \text{ kJ/kg} \cdot K \)
At the inlet 1: $P_1 = 3 \text{ MPa}$, $s_1 = s_2 = 7.6953 \text{ kJ/kg} \cdot \text{K}$ (superheated vapor since $s_1 > s_{g,3 \text{ MPa}}$)

Using the superheated vapor table and interpolation:

$$h_1 = 3682.8 + \frac{7.6953 - 7.5103}{7.7590 - 7.5103} (3912.2 - 3682.8)$$

$$\Rightarrow h_1 = 3853.4 \text{ kJ/kg}$$

At the outlet 3: $P_3 = 500 \text{ kPa}$, $s_3 = s_1 = s_2 = 7.6953 \text{ kJ/kg} \cdot \text{K}$ (superheated vapor since $s_3 > s_{g,500 \text{ kPa}}$)

Using the superheated vapor table and interpolation:

$$h_3 = 3168.1 + \frac{7.6953 - 7.6346}{7.7956 - 7.6346} (3272.4 - 3168.1)$$

$$\Rightarrow h_3 = 3207.4 \text{ kJ/kg}$$

Substituting into the energy equation:

$$-\dot{m}_1 h_1 + \dot{m}_2 h_2 + \dot{m}_3 h_3 = -\dot{W}_s$$

$$\Rightarrow -2 \times 3853.4 + 1.9 \times 2682.4 + 0.1 \times 3207.4 = -\dot{W}_s$$

$$\Rightarrow \dot{W}_s = 2290 \text{ kW}$$
**Problem 2**

1. **Entropy change for the refrigerant**
   - **State 1:** \( P_1 = 200 \text{ kPa}, \ x_1 = 0.4 \)

The properties of the 2-phase mixture can be obtained from the saturated R134a table:

<table>
<thead>
<tr>
<th>Saturated refrigerant-134a—Pressure table</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Specific volume,</strong> m³/kg</td>
</tr>
<tr>
<td>P kPa</td>
</tr>
<tr>
<td>160</td>
</tr>
<tr>
<td>180</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td>240</td>
</tr>
</tbody>
</table>

\[ \begin{align*}
\nu_f &= 0.0007532 \text{ m}^3/\text{kg} \\
\nu_g &= 0.099951 \text{ m}^3/\text{kg}
\end{align*} \]

\[ \begin{align*}
\rho_f &= 38.26 \text{ kJ/kg} \\
\rho_{fg} &= 186.25 \text{ kJ/kg} \\
\rho_g &= 224.51 \text{ kJ/kg}
\end{align*} \]

\[ \begin{align*}
s_f &= 0.15449 \text{ kJ/kg} \cdot \text{K} \\
s_{fg} &= 0.78339 \text{ kJ/kg} \cdot \text{K} \\
s_g &= 0.93788 \text{ kJ/kg} \cdot \text{K}
\end{align*} \]

The specific entropy at state 1 is calculated as:

\[ s_1 = s_f + x_s s_{fg} \]

\[ \Rightarrow \quad s_1 = 0.15449 + 0.4 \times 0.78339 \]

\[ \Rightarrow \quad s_1 = 0.4678 \text{ kJ/kg} \cdot \text{K} \]

Similarly, the specific volume of the 2-phase mixture at state 1 is calculated as:

\[ \nu_1 = \nu_f + x_s \nu_{fg} \]

\[ \Rightarrow \quad \nu_1 = 0.0007532 + 0.4 \times (0.099951 - 0.0007532) \]

\[ \Rightarrow \quad \nu_1 = 0.04043 \text{ m}^3/\text{kg} \]

The mass of the mixture is:

\[ m = \frac{V}{\nu_1} = \frac{0.5}{0.04043} = 12.37 \text{ kg} \]

- **State 2:** \( P_2 = 400 \text{ kPa}, \ \nu_2 = \nu_1 = 0.04043 \text{ m}^3/\text{kg} \)

Based on the saturated R134a property table at \( P_2 = 400 \text{ kPa} : \nu_{f,400kPa} < \nu_2 < \nu_{g,400kPa} \)

Therefore, state 2 is also a two-phase mixture.
The quality of the mixture is calculated as: 

\[ x_2 = \frac{\nu_2 - \nu_f}{\nu_{fg}} = \frac{0.04043 - 0.0007905}{0.051266 - 0.0007905} = 0.7853 \]

The specific entropy at state 2 is calculated as:

\[ s_2 = s_f + x_2 s_{fg} \]

\[ \Rightarrow s_2 = 0.24757 + 0.7853 \times 0.67954 \]

\[ \Rightarrow s_2 = 0.7813 \text{ kJ/kg K} \]

The entropy change is:

\[ \Delta S_{R134a} = m(s_2 - s_1) \]

\[ \Rightarrow \Delta S_{R134a} = 12.37(0.7813 - 0.4678) \]

\[ \Rightarrow \Delta S_{R134a} = 3.876 \text{ kJ/K} \]

2- Entropy change for the source

Let the source be the system. Assuming that the transfer of heat from the source to the refrigerant is internally reversible:

\[ \Delta S_{source} = \int_{1}^{2} \frac{\delta Q}{T} \]

Since the source has a constant temperature: 

\[ \Delta S_{source} = \frac{Q_{source, in}}{T_{source}} \]

The heat lost by the source is equal in magnitude to the heat gained by the mixture, which can be determined by applying the 1st law to the refrigerant:

\[ \Delta E = \Delta U = Q_{R134a, in} - W_{R134a, out} \]

Since the volume of the tank is constant: 

\[ W_{R134a, out} = 0 \]

\[ \Rightarrow m(u_2 - u_1) = Q_{R134a, in} = -Q_{source, in} \]

\[ \Rightarrow Q_{source, in} = m(u_1 - u_2) \]

Therefore:

\[ \Delta S_{source} = \frac{m(u_1 - u_2)}{T_{source}} \]

\[ \Rightarrow \Delta S_{source} = \frac{12.37(112.76 - 198.29)}{273 + 35} \]

\[ \Rightarrow \Delta S_{source} = -3.434 \text{ kJ/K} \]

3- Total entropy change
\[ \Delta S_{total} = \Delta S_{R134a} + \Delta S_{source} \quad \Rightarrow \Delta S_{total} = 3.876 - 3.434 \]

\[ \Rightarrow \Delta S_{total} = 0.441 \text{ kJ/K} \]

**Problem 3**

Assuming that air can be modeled as an ideal gas, the change in entropy can be expressed as:

\[ S_2 - S_1 = m \left( \int_{T_1}^{T_2} c_p(T) \frac{dT}{T} - R \ln \frac{P_2}{P_1} \right) \]

Since the process is isobaric (i.e., constant pressure): \( P_1 = P_2 \Rightarrow \ln \frac{P_2}{P_1} = 0 \)

Therefore, the change in entropy is calculated as:

\[ S_2 - S_1 = m \int_{T_1}^{T_2} c_p(T) \frac{dT}{T} \]

The mass of air is obtained from the ideal gas law:

\[ m = \frac{PV}{RT} = \frac{(120 \times 10^3) \times (300 \times 10^{-3})}{287 \times 290} = 0.4325 \text{ kg} \]

1. **Constant specific heats**

Assuming a constant specific heat for the air, this expression can be integrated as:

\[ S_2 - S_1 = mc_{p,avg} \ln(T_2 - T_1) = mc_{p,avg} \ln \frac{T_2}{T_1} \]

To determine the temperature at the end of the process, we consider the 1st law of thermodynamics applied to the air:

\[ \Delta E = \Delta U + \Delta KE + \Delta PE = Q_{in} - W_{out} \]

Assuming no change in potential energy and kinetic energy, and:

\[ U_2 - U_1 = -W_{out} \]
where \( W_{\text{out}} = (-W_{\text{elec}}) + \int PdV = -W_{\text{elec}} + P(V_2 - V_1) \)

Therefore:
\[
U_2 - U_1 = W_{\text{elec}} - P(V_2 - V_1)
\]
\[
\Rightarrow H_2 - H_1 = W_{\text{elec}}
\]
\[
\Rightarrow mc_{p,\text{avg}} (T_2 - T_1) = \dot{W}_{\text{elec}} \Delta t
\]
\[
\Rightarrow T_2 = T_1 + \frac{\dot{W}_{\text{elec}} \Delta t}{mc_{p,\text{avg}}}
\]

Substituting into the change in entropy expression:
\[
S_2 - S_1 = mc_{p,\text{avg}} \ln \left( 1 + \frac{\dot{W}_{\text{elec}} \Delta t}{mT_c c_{p,\text{avg}}} \right)
\]

**Numerical application:**
Since the final temperature of the air is not known, we must make a guess to calculate the average air temperature. Let’s assume that \( T_2 = 50°C \).

Therefore: \( T_{\text{avg}} = \left( T_1 + T_2 \right)/2 = (17 + 50)/2 = 33.5°C = 306 \text{ K} \)

Using the tables, we obtain: \( c_{p,\text{avg}} = 1.005 \text{ kJ/kg \cdot K} \)

The final temperature can now be evaluated as: \( T_2 = 17 + \frac{200 \times (15 \times 60)}{0.4325 \times (1.005 \times 10^3)} = 431°C = 704 \text{ K} \)

We update the value of the average specific heat based on this new temperature value:
\( T_{\text{avg}} = \left( T_1 + T_2 \right)/2 = (17 + 431)/2 = 224°C = 497 \text{ K} \)

Using the tables, we obtain: \( c_{p,\text{avg}} = 1.029 \text{ kJ/kg \cdot K} \)

The final temperature can now be evaluated as: \( T_2 = 17 + \frac{200 \times (15 \times 60)}{0.4325 \times (1.029 \times 10^3)} = 421°C = 694 \text{ K} \)

This updated temperature value is not substantially different from the previous iteration. We will therefore assume that \( T_2 = 421°C = 694 \text{ K} \).

Substituting in the entropy change expression:
\[ S_2 - S_1 = 0.4325 \times 1.029 \times 10^3 \ln \left( \frac{694}{290} \right) \]

\[ \Rightarrow S_2 - S_1 = 388 \text{ J/K} \]

2- **Variable specific heats**

With variable specific heats, the entropy change is expressed as:

\[ S_2 - S_1 = S_2^0 - S_1^0 - R \ln \frac{P_2}{P_1} \]

Since the pressure is maintained at a constant value:

\[ S_2 - S_1 = S_2^0 - S_1^0 = m \left( s_2^0 - s_1^0 \right) \]

Using the ideal-gas properties of air (Table A-17): \[ s_1^0 = 1.66802 \text{ kJ/kg} \cdot \text{K} \]

To determine \( s_2^0 \), we need to isolate some properties at state 2. From the 1st law:

\[ h_2 - h_1 = W_{\text{elec}} \Rightarrow h_2 = h_1 + \frac{W_{\text{elec}} \Delta t}{m} \]

Using the ideal-gas properties of air (Table A-17):

\[ h_{10\text{290K}} = 290.16 \text{ kJ/kg} \Rightarrow h_2 = 290.16 + \frac{200 \times (15 \times 60)}{0.4325} \times 10^{-3} = 706.34 \text{ kJ/kg} \]

This value of specific enthalpy is between two values in the table (702.52 < \( h_2 < 713.27 \text{ kJ/kg} \)). We use interpolation to obtain the corresponding value of \( s_2^0 \):

\[ s_2^0 = s_{702.52}^0 + \frac{h_2 - 702.52}{713.27 - 702.52} \left( s_{713.27}^0 - s_{702.52}^0 \right) \]

\[ \Rightarrow s_2^0 = 2.55731 + \frac{706.34 - 702.52}{713.27 - 702.52} \left( 2.57277 - 2.55731 \right) \]

\[ \Rightarrow s_2^0 = 2.5628 \text{ kJ/kg} \cdot \text{K} \]
Therefore:
\[ S_2 - S_1 = 0.4325(2.5628-1.66802) \Rightarrow S_2 - S_1 = 387 \text{ J/K} \]

**Problem 4**
1- **Entropy change calculation**

- **Chips**
The chips are a solid (incompressible) material. Therefore, the change in entropy is expressed as:
\[ \Delta S_{\text{chips}} = mc \ln \frac{T_2}{T_1} \]

**Numerical application:**
\[ \Delta S_{\text{chips}} = (10 \times 10^{-3}) \times (0.3 \times 10^3) \ln \frac{-40 + 273}{20 + 273} \]
\[ \Rightarrow \Delta S_{\text{chips}} = -0.687 \text{ J/K} \]

- **Refrigerant**
In the initial state, the refrigerant is a saturated liquid. When placed in contact with the chips, some of the refrigerant will vaporize. At state 2, we expect to have refrigerant as a 2-phase mixture.

The properties of the refrigerant at state 2 can be determined by applying the 1st law of thermodynamics to the combined system (i.e., chips + refrigerant):
\[ \Delta E = \Delta U + \Delta KE + \Delta PE = Q_{\text{in}} - W_{\text{out}} \]

Assuming no change in potential energy and kinetic energy, no heat transfer with the surroundings, and no work interactions:
\[ U_2 - U_1 = 0 \]
\[ \Rightarrow m_{\text{chips}} (u_2 - u_1)_{\text{chips}} + m_{\text{R134a}} (u_2 - u_1)_{\text{R134a}} = 0 \]

The 1st law applied to the chips is expressed as:
\[ m(u_2 - u_1)_{\text{chips}} = mc(T_2 - T_1) = Q_{\text{in, chips}} \]
\[ \Rightarrow Q_{\text{in, chips}} = (10 \times 10^{-3}) \times (0.3 \times 10^3)(-40 - 20) \]
This heat transfer is equal to the amount of energy needed to vaporize the refrigerant:

\[ m_{g,R134a}(u_g - u_f) = Q_{\text{as, chips}}, \]

where \( u_g \) and \( u_f \) are obtained from the saturated R134a table at a temperature of -40°C:

\[ \Rightarrow m_{g,R134a} = \frac{0.18}{207.40} = 0.0008679 \text{ kg} \]

The change in entropy for the refrigerant is calculated as:

\[ \Delta S_{R134a} = S_2 - S_1 = \left( m_{g,R134a} s_{g,2} + m_{f,R134a} s_{f,2} \right) - m_{f,s} s_{f,3} \]

\[ \Rightarrow \Delta S_{R134a} = \left[ 0.0008679 \times 0.96866 + (0.005 - 0.0008679) \times 0 \right] - 0.005 \times 0 \]

\[ \Rightarrow \Delta S_{R134a} = 0.841 \text{ J/K} \]

- Total entropy change

\[ \Delta S_{\text{total}} = \Delta S_{R134a} + \Delta S_{\text{chips}} \Rightarrow \Delta S_{\text{total}} = 0.841 - 0.687 \Rightarrow \Delta S_{\text{total}} = 0.154 \text{ J/K} \]

2- The change in total entropy is positive \( \Rightarrow \) some entropy is generated \( \Rightarrow \) This process is physically possible.